TMO TECHNOLOGY DEVELOPMENT PLAN

Optical Communications Work Area

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OBJECTIVE:
The objectives of this work area are to assess, develop and demonstrate reliable and cost-effective optical communications and tracking capabilities, and to work with TMOD and NASA for the timely and affordable establishment of an optical DSN capability for supporting future NASA missions.

GOALS and SIGNIFICANCE:
Provide a low-cost ground station infrastructure that will build useful experience for network operations and support to future flight demonstrations, conduct cost-effective system-level demonstrations that will validate technology performance projections, assess atmospheric effects on optical comm link performance so that availability and link margins can be accurately bookkept, and develop automated analysis tools to save time and increase accuracy of optical link analyses.

PRODUCTS:
Low-cost ground stations, affordable end-end link systems demonstrations, optical atmospheric visibility models and improved link performance analysis tools.

DESCRIPTION:
Optical communications offers significant improvements for DSN-supported service. However, the performance of the technology and the values of the improvement predictions need to be well understood. Additionally, the impacts of the atmosphere must be well calibrated. The Visibility Monitoring work unit provides the means to gather in-situ data on the effects of cloud or other weather outages. Additionally, the impact of atmospheric turbulence, and our ability to compensate for such effects, is being evaluated and demonstrated in the Adaptive Optics work unit. Results from these work units are being folded into a set of user-friendly analysis tools that will more cost-effectively predict system performance. Finally, the Optical System Demonstrations work unit will validate end-end optical communications performance. These validations will be done initially in a ground-to-ground link setting, then using an air-ground link, and finally in space-to-ground links. The results of these activities are being used directly to formulate and update the long-range optical communications roadmap, which in turn is being used to coordinate with TMOD implementation organizations and the NASA sponsors for the implementation of an operational NASA optical communications capability.

DELIVERABLES:
A released version of the ATLAS ACK/TRK analysis program, completion of the performance upgrades for the three AVM observatories, an assessment of the impacts of outsourcing the AVM program, a demonstration of the OCD optical terminal performance between TMF and Strawberry Peak, initial preparations for an air-ground demonstration and a requirements document for the adaptive optics subsystem for the 1-m R+D optical station.

RESOURCE REQUIREMENTS BY WORK UNIT:

	JPL Account #	FY98	FY99	FY00	FY01	FY02	FY03
Adaptive Optics	412-47002	100					
Opt Sys Anal Tools	412-47003	200					
Visibility Monitor	412-47004	200					
Opt Comm Demo	462-42014	500	800	1000	800	800	800
Total		1000	1400	1700	1600	1629	829
Total Workforce							

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: Adaptive Optics Atmospheric	
WORK UNIT IN WHICH FUNDED: Adaptive Optics Atmospheric 412-47002-0-3310	
WORK AREA: Optical Communications	

BRIEF TECHNICAL SUMMARY:

The objective of this work unit is to develop adaptive optics systems technology for optical signal wavefront control, and to demonstrate its performance benefits for removing the effects of atmospheric turbulence on NASA optical communications links.

JUSTIFICATION AND BENEFITS:

Optical beams experience wavefront distortions when transmitted through the atmosphere. These effects are of less importance when introduced on a downlink beam (if the signal is detected using direct detection) since the reception aperture is usually large and averages out these effects. However, atmospheric turbulence has a significant impact on uplink beams since the effects occur early in the transmission path. Turbulence-induced phase distortions can reduce the "effective" transmitting aperture size, thereby creating the need for more uplink laser power. Adaptive optics has the ability to sense the atmospheric phase distortions in real time, and by predistorting the transmitted optical wavefront, compensate for the atmospheric losses. This relaxes the requirement for ground transmitter station laser power, or extends the range over which a given laser beam can be propagated.

Correcting atmosphere-induced phase front distortions also opens new options for optical communications, e.g., heterodyne detection. Direct detection schemes are more succeptible to high background noise environments than heterodyne detection and they impose a greater limit on the Sun-Earth-Probe (SEP) angles at which spacecraft links can operate. One such mission is the Solar Probe mission. Recently the Solar Probe study team has expressed interest in optical communications because it will reduce the size of the telecom system, especially the antenna. Since spacecraft subsystems must be shielded from the sun for thermal reasons, reducing the telecom size also reduces the mass of the requisite shielding. To utilize optical communications from a mission so close to the Sun, the narrow-band filtering effects of coherent detection are required. With a mission like Solar Probe, the mission link requirements can be supported by ground telescopes in the 1-m category, This is small enough that an adaptive optics system could be implemented, thereby allowing coherent optical reception.

This work unit will provide the technology and performance measurements required to validate these improvements

APPROACH AND PLAN:

Over the next three years the plan is to begin development of an AO system with the intention of demonstrating AO limited capability at JPL by the end of FY '00. In FY'98, the plan calls for letting a contract to industry to perform a system definition study that will define the best way to implement AO capability at TMF. We also plan to procure a deformable mirror in this year. The control electronics and computer interface will be procured in FY'99. In FY'00 we plan to procure the low noise camera.

DELIVERABLES:

Prepare contract to industry to provide system definition of AO subsystem	Mar '98
Procure deformable mirror	Mar '98
Procure drive electronics and computer control algorithms	Mar '99
Prepare test proceedures for AO system evaluation	Jan '99
Integrate and test mirror and electronics	Sept '00

RESOURCE REQUIREMENTS:

	Prior Year	FY98	FY99	FY00	FY01	Total at Completion
Funding ($K)		100				100
Workforce (WY)		0.5				0.5
Co-funding ($K)						0
Projected Savings ($K)						0

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: Optical Systems Analysis Tools	
WORK UNIT IN WHICH FUNDED: Optical Systems Analysis Tools 412-47003-0-3310	
WORK AREA: Optical Communications	

BRIEF TECHNICAL SUMMARY:
The objective of this work area is to develop optical communications analysis tools that will permit more efficient and more accurate estimation of link performance parameters. These tools include communications link design and error performance prediction analysis, acquisition and tracking performance analysis, and simulation systems for optical communications subsystems.

JUSTIFICATION AND BENEFITS:
An ever-increasing set of requests for analyses of optical communications links have been received from a variety of mission planners. These missions include robotic deep-space missions (Europa Orbiter, Pluto Express, Champallion, Solar Probe, DS3, DS4), human exploration (precursor) missions (Mars 03, Mars Express), and Earth-orbital missions (EOS, EO2, Shuttle, Space Station, LightSAR). Many of these missions initially ask for quick (approximate) analyses of performance capability, mass, cost, power consumption, etc. Then, as they become more serious about the use of the technology, they require more in-depth studies of these parameters. Even the design trades and baseline changes within a single mission can result in the need for many new performance prediction analyses. Thus, automated tools that can efficiently support these requests, and which can remove the variability that results from non-uniform assumptions, are greatly needed. Additionally, as the acceptance and utilization of optical communications becomes more widespread, it is necessary to design these tools so that they can be operated by missions planners and systems engineers, rather than only by the optical communications specialists.

This work unit will develop automated analysis and simulation tools that will improve the efficiency and accuracy of optical communications link analyses, and will transition those tools to the system designers' tool chests. The programs will extensively utilize user-friendly graphical user interfaces (GUI's) to permit the occasional users to quickly configure and analyze candidate links. They will also allow the optical communications specialists to include more of the system and environmental influences, thereby allowing more accurate analyses to be performed.

APPROACH AND PLAN:
During FY'97, the Free-space Optical Communications Analysis Software (FOCAS) was developed. The program is Excel-based, and uses a Visual Basic interface. The targeted user base for the software includes the mission planners and system engineers of Team X, the interested technical non-specialists who wish to learn more about optical communications, and the technology specialists who need to perform more link analyses in less time. The beta version of the software was released in mid-1997, and modifications resulting from the beta testing will be incorporated into Version 1.0 of the software, planned for release near the end of the FY. Several incompatibility issues between computer platforms and Excel software versions have been experienced. These have been traced to bugs in the MicroSoft Excel software that the manufacturer has fixed (or plans to fix). After release of FOCAS Version 1.0, the software will be maintained and a record of potential upgrades (to be implemented on a semi-annual basis) will be kept.

The FOCAS program is restricted to the optical communications link analysis, allowing the design parameters to be specified and the resulting link performance and margin to be calculated. However, this program does not address the spatial acquisition and tracking (ACK/TRK) performance of the specified links. Currently, the requirements for an ACK/TRK analysis program are being studied and will lead to the development of the (beta version of the) ACK/TRK Link Analysis Software (ATLAS) during the first half of FY'98. ATLAS will include analyses for both point-source (beacon laser) tracking, as well as extended-source (e.g. planetary object) tracking. Performance metrics for ATLAS will include acquisition time statistics, tracking jitter variance, probability of tracking fade drop-outs to a specified intensity level, and mean-time-to-loss-of-track. The beta version of ATLAS will be evaluated during the second half of FY'98, at which time ATLAS Version 1.0 will be released.

Additional analysis tools that will be developed include an optical two-way ranging link analysis program, and simulation modules for use with SPW simulators.

DELIVERABLES:

Release of FOCAS Version 1.0	- September 1997
Semi-annual updates of FOCAS	- March 1998 and September 1998
Beta version of ATLAS released	- March 1998
ATLAS Version 1.0 Release	- September 1998
Development of Optical Ranging Analysis Software	- June 1999
Development of SPW-based end-end simulation	- July 2000

RESOURCE REQUIREMENTS: (Prior name for this work unit is "Optical System Studies").

	Prior Year	FY98	FY99	FY00	FY01	Total at Completion
Funding ($K)	310	200				510
Workforce (WY)	1.7	1				2.7
Co-funding ($K)						0
Projected Savings ($K)						0

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: Atmospheric Visibility Statistics and Modeling	
WORK UNIT IN WHICH FUNDED: Atmospheric Visibility Statistics and Modeling 412-47004-0-3310	
WORK AREA: Optical Communications	

BRIEF TECHNICAL SUMMARY:
The objective of this work unit is to develop and validate models for the impacts of the atmosphere on optical signal reception and transmission. The current emphasis of this work unit is on the validation of atmospheric (primarily cloud) attenuation models through data collected by the network of Atmospheric Visibility Monitoring (AVM) observatories. Future efforts in this work unit will address atmospheric-induced phase and amplitude scintillation models.

JUSTIFICATION AND BENEFITS:
One of the most significant items influencing the performance of space-ground optical communications links is the impact of the atmosphere, most notably atmospheric attenuation due to clouds and particulates. Accordingly, a major emphasis in this work area is placed on the collection and analysis of data that will permit the modeling of atmospheric attenuation. The combination of in-situ attenuation data collected by the AVM network, global remote sensing data collected by satellite-based sensors, and theoretical modeling based on atmospheric physics, will permit the generation of attenuation models in which there is high confidence. and the results of those models will be validated through subsequent systems demonstrations. The characterization and validation of atmospherically-induced amplitude and phase scintillation models are also important as they represent the next most significant uncertainty in the overall link performance models.

APPROACH AND PLAN:
The first task in FY’98 is to complete the upgrade of the AVM unit at Table Mountain Facility (TMF) which commenced in FY’97. This includes integration of the new hardware (computer, CCD camera, network connections) and final on-site testing of the newly developed software. After ensuring proper operation of the upgraded system at TMF, the Goldstone and Mt. Lemmon AVM units will be upgraded as well. The upgrades are primarily intended to improve the quality of visibility data at the 1.06 um wavelength and data collected during daytime. The new computers also allow on-site processing of the data to significantly reduce data transferred over modem, and thus reduce downtime. As part of the upgrade, bad or decaying cables will be replaced to increase the life of the system.

As has been in the past, the Optical Visibility Monitoring work unit will provide routine maintenance for the three stations, and will continue to collect and process atmospheric transmission data. A user-friendly AVM visibility database developed in FY’97 using Microsoft Access will greatly aid in rapidly turning raw data into useful plots. We will also investigate the possibility of extracting seeing and background radiance values from the AVM data.

Towards the later part of FY’98, we will investigate the possibility of outsourcing the operation of the three AVM units. Outsourcing of AVM operation will enable JPL staff to concentrate on data analysis and free them from day-to-day maintenance of the facilities. Furthermore, data from weather satellites and meteorological instruments will be compared & correlated with data taken at the AVM stations to provide insight into how data may be used to develop an AVM-type statistical model for atmospheric visibility around the globe.

In future years, modifications will be considered to extend the AVM’s spectral detection range further into the IR, particularly to 1550 nm, the operating wavelength of the Erbium-doped fiber amplifier. At these IR wavelengths the atmospheric transmission is higher than in the visible, and both the atmospheric scintillation effects and the sun’s irradiance, i.e. sky background noise, are lower than at visible wavelengths. Space-to-ground optical links could benefit significantly from rapid developments of laser and detector technologies around the 1550 nm wavelength, developments that are being driven by the long-haul-link fiber-optic needs of the telephone companies.

DELIVERABLES:

Complete upgrade installation/testing at TMF AVM site	10/97
Complete upgrade of Goldstone AVM site	12/97
Complete Upgrade of Mt. Lemmon AVM site	1/98
Complete evaluation of AVM outsourcing	9/98

Quarterly visibility model updates	
First quarter FY’98	1/98
Second quarter FY’98	4/98
Third quarter FY’98	7/98
Fourth quarter FY’98	10/98

RESOURCE REQUIREMENTS:

	Prior Year	FY98	FY99	FY00	FY01	Total at Completion
Funding ($K)	181	200				381
Workforce (WY)	0.9	1				1.9
Co-funding ($K)						0
Projected Savings ($K)						0

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: Optical Communications Systems Demonstrations	
WORK UNIT IN WHICH FUNDED: Optical Communications Systems Demonstrations 462-42014-0-3310	
WORK AREA: Optical Communications	

BRIEF TECHNICAL SUMMARY:
The objective of this work unit is to conduct a series of end-end optical system technology demonstrations that will validate the performance of optical communications systems and which will build confidence in the maturity of the technology.

JUSTIFICATION AND BENEFITS:
The thrust in future missions is to smaller spacecraft while, at the same time, the need for more communications capability continues to climb. Optical communications offers the advantage of a smaller spacecraft communications terminal (at less than half the mass) while, at the same time, providing a factor of 10-100 increase in data return rate compared to conventional rf communications. Lower mass and higher communications rates are benefits that are directly translated into dollars saved in launch costs and tracking operations time. The ACBS (Advanced Communications Benefits Study) results showed that for Mars missions with average data volumes from 0.1 to 10 Gbits per day, and assuming no infusion of new optical communications technology, optical communications flight hardware is lighter by as much as 40% in some cases than either X-Ka or X-X systems, and current indications are that the cost of the ground infrastructure can be recouped from reduced operational costs over as few as 4-10 missions.

To guarantee that these savings are really available in operational systems, it is necessary to validate the system-level projections in end-end link demonstrations. This work unit will provide those demonstrations. Additionally, this work unit will also provide valuable experience in the operational aspects of optical communications tracking and data extraction. This experience will be invaluable to the future optical communications mission designers and ground operations personnel.

APPROACH AND PLAN:
There are a number of incremental system-level demonstrations that are planned. All of these assume the use of the Optical Communications Demonstrator (OCD) terminal, being developed under Code S funding. The first demonstration will be a ground-ground demonstration. It assumes that the OCD will be installed at Strawberry Peak (42 km to the East of TMF) and will be mounted on a spacecraft jitter simulation platform. The existing TMF 0.6-m diameter telescope will be used at the other end. The interconnecting path is largely at a high altitude above the ground, thus minimizing the amount of ground turbulence. To overcome any residual scintillation fluctuations, the TMF telescope will transmit a multi-beam array of beacon laser signals toward the Strawberry Peak site. The return beam from the OCD will be received by the 0.6 m diameter telescope, which has sufficient collection area to aperture average out the fluctuations in the other direction. The TMF-Strawberry Peak demonstration will be used to test out both the OCD terminal and the TMF ground site equipment.

Following the ground-ground demonstration, there will be an air-to-ground demonstration. This will be accomplished by flying the OCD terminal in an appropriately-modified aircraft and transmitting to the telescope at TMF. After successful completion of the air-ground demonstration, the OCD hardware will be further qualified for space flight and the air-ground link will be extended to a space-ground link. Studies and programmatic negotiations are underway to define this, and a possible subsequent, flight demonstration.

DELIVERABLES:

Preparation of OCD for GND-GND demo	12/97
Preparation of TMF facility for GND-GND demo	1/98
Completion of TMF-Strawberry Peak link demo	3/98
Complete TMF-Strawberry peak data analysis	9/98
Completion of air-ground link demo	5/99
Completion of first space-ground link demo	11/99

RESOURCE REQUIREMENTS:

	Prior Year	FY98	FY99	FY00	FY01	Total at Completion
Funding ($K)		500				500
Workforce (WY)		3				3
Co-funding ($K)						0
Projected Savings ($K)						0